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SCIENCE

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FRIDAY, JANUARY 25, 1901.

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MSS. intended for publication and books, etc., intended for review should be sent to the responsible editor, Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE ORIGIN, SCOPE AND SIGNIFICANCE OF BACTERIOLOGY.*

BACTERIOLOGY is a child of the 19th century. It is the offspring of chemistry and biology, enriched by physics with the gift of the achromatic microscope.

By the end of the first quarter of the century, natural philosophy, natural history and chemistry had almost wholly displaced the magic and alchemy of the Middle Ages and the Renaissance. Natural law was the explanation indicated by natural knowledge for natural phenomena, and in most cases a natural explanation of these phenomena was either discoverable or conceivable. The Copernican theory, as developed by Galileo, Kepler, Newton and their successors, accounted satisfactorily for the obvious structure and operation of the solar system. The researches of Vesalius and Harvey, and their successors, had made comprehensible the anatomy and physiology of the animal body. The earth, in response to the inquiries of Hutton and Lyell, was yielding up the record of its slow but sublime history, its very rocks bearing eloquent testimony to their natural origin. The lightning of heaven, the thunderbolt of Zeus, interrogated by our own Franklin, had confessed its affinity

* Address delivered by the president before the Society of American Bacteriologists, Baltimore, December 27, 1900.

to the humbler electricity of glass and amber. Everywhere the growth of natural knowledge revealed always more and more of natural law. Magic and mystery in the greater part of the macrocosm and microcosm were no more. Alchemy, the philosophers' stone and the transmutation of metals were gone forever. Yet even as late as 1835 there still remained one large group of familiar natural phenomena which was neither understood nor explained.

Fermentation, and especially alcoholic fermentation, had long excited the wonder of the ignorant, the curiosity of the wise. Fermentation was obviously the seat of active, spontaneous, self-regulated change. Its bubbling had given to it the name, which comes from the Latin *fervere*, to boil. Yeast was the constant accompaniment of the alcoholic fermentation, but exactly what yeast was no one knew. At best it seemed to be a consequence rather than a cause of fermentation, since it was more abundant at the end than at the beginning, more abundant in the later and less active stages than in the earlier and more active. Leeuwenhoeck indeed had examined yeast microscopically and found in it what seemed to be living cells, but his discovery appears to have occasioned no great surprise and to have been virtually forgotten after the lapse of a hundred and fifty years. The bubbling or boiling of the alcoholic fermentation suggested the action of acid on limestone, but as there was no limestone present and very little acid the suggestion explained nothing and was not very helpful. Chemistry had dealt with the alcoholic fermentation, and had come to the conclusion, based upon analyses and experiments, that it was a purely chemical process, in which sugar was decomposed wholly into alcohol and carbonic acid, the cause of the decomposition being the aggressive action of the oxygen of the air.

These were the days in which oxygen

was much in fashion, for it had been only recently discovered by Priestley in 1774, and it was perhaps natural that Gay Lussac, reflecting upon the successful experiments by Appert in preserving foods by canning, should have concluded that it was the exclusion of the atmospheric oxygen from the tins which prevented fermentation of the fruit juices which they contained. He was confirmed in this opinion by his own experiment upon grape juice in the Torricellian vacuum, and his theory was, naturally enough, accepted and extended by his pupil Liebig. There were not wanting, however, objectors to this theory, nor experiments which seemed to disprove it, and it was never very satisfactory because it failed to account adequately, not only for the constant presence and growth of yeast—for which no provision was made in Gay Lussac's formula,—but also because of the total absence of oxygen in the most active stages of alcoholic fermentation as conducted in breweries, etc. For most persons, therefore, fermentation was still an unsolved problem when, in 1836, Schulze completely disproved the oxygen theory by showing that ordinary air, such as had been excluded in the experiments of Appert and Gay Lussac, was unable, even if admitted, to produce fermentation if it had first been caused to bubble slowly through concentrated sulphuric acid which, whatever else it might do, certainly could not deprive it of oxygen.

Putrefaction was another unsolved problem in nature, not only at the beginning of this century, but as late as 1835. It obviously resembled fermentation in some respects, and had often been classified with it, but yet it was also obviously different. Bubbling was not always an accompaniment of it, and the microscopes of the day, comparatively poor as they were, had revealed the almost constant presence in putrefactions of swarms of microscopic

forms of life roughly classified as 'animalcules.' These were either not present at all in the alcoholic fermentation or, if present, were few in number. Moreover, in this case also, the microscopic life seemed to be a consequence rather than a cause of putrefaction, inasmuch as it was most abundant, not at the beginning, but toward the end of the process. Meat kept in warm air or warm water soon 'spoiled,' though exactly how or why no one knew. Chemical changes were obvious and abundant, but of a totally different kind from those characterizing the fermentation of alcohol or vinegar.

Organic decomposition and decay, two of the most widespread and universal processes in nature, while occurring on every hand, were in the early part of our century either not understood or else incorrectly interpreted. The slow decay of timber and of teeth, the rapid decay of fruits and flowers, sometimes, it is true, suggested putrefactions, but quite as often went on almost insidiously and unobserved. Even after the first quarter of our century had gone by, slow decay was given a very large name, *eremacausis*, but yet was only imperfectly understood. The current explanation, such as it was, was in harmony with the few facts established by chemistry, viz., a theory of oxidation probably produced by the aggressive energy of free oxygen. Iron rusted readily enough; why should not wood and teeth and fruits 'rust' also in a somewhat different, but still essentially similar, way. This hypothesis seemed to be confirmed by the fact that canned fruits and foods were preserved so long as air was excluded from them, but spoiled soon after being exposed to the atmosphere. It was not observed, or if observed it was forgotten or believed to be immaterial, that meat and fish and fruits could be equally well preserved for an indefinite length of time by simple drying, although remaining constantly exposed in the dry condition to

the aggressive action of the free oxygen of the air.

Nitrification, or the conversion of nitrogenous organic matter into mineral nitrates, was well known in the early part of our century as one of the most fundamental processes in nature and of prime importance in agriculture; manures, for example, being nitrified before they could become fit food for green plants. Precisely how this nitrification was effected, however, was not known, although it was suggested that free oxygen somehow oxidized organic nitrogen by a process similar to that in which it attacks iron. Obviously, this process went on best, if not exclusively, in the soil, for organic nitrogen elsewhere showed little or no tendency to unite with oxygen to form nitrates. The soil seemed to have some peculiar property of favoring this oxidation, but exactly what this property could be, unless it were a kind of platinum-sponge effect, was by no means clear even to the most eminent chemists and naturalists.

Natural 'heating' and 'sweating' were processes familiar enough to all observers of natural phenomena, but exactly what they meant no one in the early part of our century knew. Hay, imperfectly cured, heated and even rotted in the barn. Manure, collected in heaps, underwent a spontaneous and peculiar change by which it was altered or ripened, sometimes becoming intensely hot and giving off vapors which indicated profound and important chemical changes. Flax, in the course of the preparation of linen fiber, was made to undergo a peculiar maceration or change which must have suggested fermentation or decay and was known as rotting or 'retting.' Hides, in the peculiar and primitive processes preliminary to tanning, often underwent a similar change known as 'drenching.' Tobacco 'sweated,' and milk 'soured,' spontaneously. Cider 'turned' into vinegar, grape-juice into wine, and in various other domestic or indus-

trial processes advantage was taken of 'spontaneous' changes of highly peculiar and unexplained characteristics.

Contemporary spontaneous generation, in the first half of our century, was commonly accepted as a fact even by many scientific men, who held that it was the simplest explanation of the origin of the swarms of microscopic organisms observed in putrefying liquids or infusion. The belief in easy and constant spontaneous generation of living from lifeless matter is probably as old as the human race, and if we bear in mind the ignorance which was universal concerning the nature and complexity of even the simplest forms of life, and the complete lack of trustworthy evidence such as we have to-day against the theory of present-day abiogenesis, we can not wonder that this theory should have been so recently and so widely held. It is true that some of the most acute observers, such as Leeuwenhoek, had utterly refused to accept the theory, arguing that the total absence of abiogenesis in the higher forms of life made its occurrence in the lowest forms highly improbable, but we must admit that in these cases their conclusions were based rather upon instinct than scientific evidence. Granting, as we must, the theoretical possibility, and perhaps probability, of this process in the primordial origin of life upon our globe, we may well be slow to condemn those who leaned toward the theory of modern spontaneous generation as the most reasonable explanation of the myriad life of to-day in the under microscopic world. At the same time it can hardly be doubted that the belief in present-day spontaneous generation represented the last survival of such traces of belief in magic, alchemy, and the transmutation of metals, as the nineteenth century inherited from its predecessors.

In the early part of our century there was a group of natural phenomena of a

different order, which, though painfully familiar, was equally puzzling and mysterious. Seemingly spontaneous in origin, always inexplicable, erratic and mysterious in transmission, often swift in operation and fatally destructive to human life, the mysterious phenomena known as *epidemics*, *plagues* and *pestilences* were among the most dreaded of all natural occurrences. Many indeed still spoke of them as 'visitations of the Almighty,' and treated them as if they were of superhuman origin, but Dr. William Farr, in preparing a classification of diseases for the purposes of the registration of vital statistics—made for the first time in history on a large scale in England in 1839—recorded epidemics, plagues and pestilences as strictly natural phenomena, though obscure, and while specifically denying any intention of considering them as fermentations, almost unconsciously acknowledged their affinity to fermentations by the name which he applied to them, and under which they have ever since been known, viz., the 'zymotic' or fermentative diseases. Dr. Farr gives no theory of their origin or causation and expressly declines to regard them as fermentations, partly, no doubt, because of the vehemence of Liebig, who was opposed to the idea, but also, we may believe, because the prevailing theory of the cause of fermentation was that it was due to the aggressive energy of free oxygen; and it would have been obviously too absurd to assert that free oxygen, the very breath of human life, is at the same time the cause of its worst diseases. In Germany, Henle arrived, largely from observation and *a priori* reasoning, at a conclusion essentially similar to Dr. Farr's, and, in America, Professor J. K. Mitchell, father of our distinguished physiologist and litterateur, Dr. Weir Mitchell, was urging, upon similar grounds, his able thesis 'On the Cryptogamous Origin of Malarious and Epidemic Fevers.'

To recapitulate.—While, in the first half of our century, the anatomy and physiology of the macrocosm and the microcosm, the heavens, the earth and man, were fairly well understood, there yet remained certain important natural phenomena either generally not understood at all or else, as we know, almost completely misinterpreted, namely, as follows :

1. Fermentation of every kind.
2. Putrefactions.
3. Organic decomposition and decay.
4. Nitrification.
5. The origin of microscopic life.
6. Zymotic diseases.

The end of the third decade of our century saw the beginning of a profound change in the accepted theories concerning all or nearly all of these phenomena. In 1836, Schulze proved that the oxygen theory of fermentation could not be correct. The next year Theodor Schwann confirmed his results by a different experiment, and by the improved achromatic microscope not only discovered, or rediscovered, the yeast plant, but also boldly asserted that the life and growth of this plant was the cause, and not the consequence, of the alcoholic fermentation. Thus, based on solid grounds, began the biological or germ theory of fermentation of which Schwann is entitled to be regarded as the founder, precisely as Pasteur some twenty years later became the founder of its direct descendant, the germ theory of disease. Confirmed or even slightly anticipated by Latour in his discovery of the living and vegetable character of yeast; supported by Helmholtz and Mitscherlich in his assertion that no alcoholic fermentation of sugar ordinarily occurs except as caused by yeast; and by Schroeder and Von Dusch in his claim that the cause of fermentation and putrefaction in boiled liquids is not air, but floating matters in the air; Schwann is entitled to be regarded as the immediate precursor of the

bacteriologists and as having effectually paved the way for the first and greatest of all bacteriologists, Louis Pasteur.

Of Pasteur, the founder of our science, I shall only recall very briefly the principal facts of history :

Pasteur brought to the study of all the problems that I have enumerated—and I hardly need remind you that among them are some of the most elusive, some of the most profound, and some of the most intensely practical, problems in all the field of natural knowledge—a thorough working familiarity with physics and chemistry. Though not exactly a chemist, he was able to meet chemists upon their own ground. Though not exactly a microscopist, he was highly trained in physics and mineralogy, and thus quickly became a master of the microscope. Piqued by the fact that living ferments could do with his salts what he himself could not do, he began a careful study of ferments and fermentation, with the result that in a few short years he had completely confirmed and established the biological or germ theory of fermentation propounded by Schwann; had extended it so as to make it include putrefactions; had shown that organic decomposition and decay in nature are simply slow fermentations or putrefactions; had nearly, if not quite, overthrown the world-old theory of spontaneous generation; had studied the floating matter of the air, and actually found in it organized corpuscles, or germs, of molds and of infusorial or fermentation animalcules; had invented and introduced for the first time methods for the cultivation, and even for the pure cultivation, of living ferments which so much facilitated the investigation of microscopic life that we now rightly regard them as constituting the very basis and essence of bacteriology,—which thus becomes a kind of microscopic gardening or horticulture of the microscopic world; had also, by the use of these

novel methods, established not merely the fact that living ferments in general are the cause of fermentation in general, but, what was of equal or even greater importance, the existence of specific or characteristic ferments for particular fermentations, one, for example, producing the alcoholic fermentation, another the lactic, a third the butyric, a fourth the acetic, and so on. If to-day we have to modify this primitive simplicity of arrangement and refer rather to one group of ferments than to one species merely, nevertheless the idea of specific energies for specific ferments remains secure and underlies most of the practical work of bacteriology.

Finally, through his work on industrial micro-biology, on the yeasts and the ferments of milk, vinegar, etc., Pasteur was led not only to consider the applications of bacteriology to the useful arts, but also to study the ailments of fermented drinks and the causes of their deterioration or 'disease,' with the result that in discovering and proclaiming the sources of the diseases of wine and beer as residing in specific noxious ferments or germs carelessly or unwittingly introduced, he became, almost unconsciously, not merely the apostle and defender of the biological or germ theory of fermentation, but also the principal contemporary exponent of the biological or germ theory of disease; a theory which had long been a dream of pathologists and now suddenly rose into scientific as well as popular favor.

Such was the origin of bacteriology, and such were some of the early achievements of its great founder. Stimulated by the work of Pasteur, a host of eager and enthusiastic workers threw themselves with intense zeal into the study of the micro-organisms which constitute the field of micro-biology. Time has proved beyond all peradventure that the foundations laid by Pasteur were laid solidly and securely. The *fermen-*

tations are in fact what he and his precursor Schwann believed them to be, viz., chemical changes produced by living ferments, which, taken together, we may call microbes. *Putrefactions* are, as Pasteur believed them to be, essentially anaërobic fermentations. *Present-day spontaneous generation* is, as Pasteur claimed, a myth—the last survivor of the notions of the alchemists. *Organic decomposition and decay* in nature have been found to be simply slow fermentations and putrefactions. *Nitrification*, or the natural mineralization of organic matter, is essentially an oxidizing fermentation, as is also, for example, the making of vinegar, from alcoholic cider. The *infectious or zymotic diseases* are either harmful fermentations, or the results of such fermentations, occurring not merely in wine, beer and vinegar, but, as Pasteur himself showed in the case of the silk-worm, in or upon the animal—and, we may now add, the plant—body.

A careful review of the subject from our present relatively advanced position shows that the really distinguishing characteristic of bacteriology is not merely its subject matter but its methods, not so much the peculiar organisms with which it deals—interesting and important though these are—as the peculiar means it has devised and employed for studying these organisms. In this respect bacteriology differs widely from any other science bearing the name of a particular class of plants or animals. Sciences such as mammalogy, ornithology, entomology, dendrology, pteridology, bryology, algology, mycology, lichenology and the like are chiefly, though not exclusively, characterized by the peculiarities of the special forms of life with which they deal, the methods by which they are pursued being largely common to all or at least in no great degree either peculiar or extraordinary. In bacteriology, on the contrary, owing, no doubt, to the small size and ap-

parent similarity of the organisms concerned, the ordinary methods of study and of classification are quite insufficient, so that new and highly peculiar methods have been devised and employed. Bacteriology does not depend, as ornithology and entomology chiefly do, on the external and internal anatomical features of individuals, but only to a small extent on these, and chiefly on the behavior of flocks, swarms, groups or masses of individuals, and upon these not in a state of nature but artificially massed or cultivated. Bacteriology finds its closest analogy not in such sciences as ornithology or bryology—the science of birds or the science of mosses—but in such sciences as breeding, gardening or agriculture. Possibly bee-keeping (apiculture) offers an analogy as useful as any. In apiculture bees are dealt with not so much as individuals, as communities or ‘colonies,’ and the swarms are bred, cared for or cultivated largely as masses and by methods highly peculiar. Bacteriology is a kind of microscopic horticulture or apiculture, and its methods, introduced in the first instance by Pasteur for yeasts and twenty years later vastly improved by Koch, are applicable to many bacteria and yeasts—though certainly not equally to all—and also to some molds and other fungi, and, to some extent, to certain algæ and protozoa. If we define as micro-organisms or microbes all organisms invisible or barely visible to the naked eye, we may conveniently describe their study as micro-biology. *Bacteriology* then is a sub-division of micro-biology and is conveniently defined as *the science of the culturable micro-organisms*.

Enough has perhaps been said already, in dealing with the origin of bacteriology, to indicate sufficiently the scope and significance of the culturable micro-organisms in nature. But when we reflect upon the simple fact that without their activity the habitable world and the sea would become

one vast charnel-house, because there would be no adequate agency for mineralizing dead matter, we begin to realize the enormous importance of the part which they play in the economy of nature. We have only to think of their helpful and wholesome unseen activity in removing from our view the dead animal bodies which would otherwise cover the earth, the dead leafage of the autumn, the worn-out trunks of trees, and the waste matters of human and animal life, in order to appreciate in some measure their fundamental importance in nature. When to this we add their tendency to cause the destruction of valuable organic matters, such as food and timber; their function in producing those fermentations, putrefactions and poisonings of the human body which we know as epidemics, plagues, pestilences, infectious diseases, suppurating wounds, gangrene and the like; when, furthermore, we consider their causative participation in such universal, familiar and important processes as bread-making, brewing, vinegar-making, the fermentations of milk and its products, butter-making, cheese-making, lactic acid manufacture, tanning and nitrification, we are in a position to understand something of the scope and significance of the culturable micro-organisms, and therefore of bacteriology, from a practical point of view. And while we cannot forget that our science had its most fruitful beginnings in pure science at the hands of a physiologist, Schwann, and a natural philosopher, Pasteur, we must allow that its highest cultivation and its richest fruits have come from the labors of medical men. The names of Lister, Burdon-Sanderson, Koch, Behring, Roux and many others are the most famous, and their wonderful researches, with the brilliant practical results of their labors for human welfare and progress, by far the most splendid achievements of bacteriology in the last

quarter of our century,—the post-Pasteur period.

But in the last analysis it is the higher significance of bacteriology which must always be regarded as its most important characteristic. By virtue of the discoveries upon which it was founded, to which it has led and upon which to-day it rests illustrious and secure, mankind has been enabled for the first time to arrive at an adequate comprehension and understanding of the microscopic world and of many important and familiar natural phenomena hitherto either not understood or misinterpreted. The origin of bacteriology is interesting and instructive; its scope is broad and comprehensive; but these matters are of only moderate consequence as compared with its philosophical significance. At the beginning of our century, in absolute ignorance of bacteriology and its wonderful teachings, man gazed with wonder or indifference on some of the most familiar, yet most mysterious, of natural phenomena. Organic matters almost everywhere slowly 'decayed' and disappeared; sweet and sugary fruit juices 'turned' rapidly and 'spontaneously' into pungent or acid liquors; slow and innocuous 'decomposition' often gave place to foul 'putrefaction' and rapid 'decay' or destructive 'rots'; manure applied to land, even to land lying fallow, soon vanished altogether; 'epidemics,' 'plagues' and 'pestilences' swept over the earth, and man could neither understand, nor explain, nor intelligently fight them; the microscopic world quivered with forms of life which seemed to be born in a day and to disappear like dew. The heavens had long since revealed the glory of God, and the firmament,—thanks to the interpretations of Copernicus, Galileo and Newton,—had abundantly shown his handiwork. But the microscopic world still sat in the shadow of darkness, awaiting the disclosure of its meaning. At last, in the fulness of time and largely

through the achromatic objective, a great light shone upon and from the under world. The mysteries of fermentation, putrefaction, organic decomposition, decay and the mineralization of organic matters were reduced to their lowest terms and brought into line with other problems of biology. Epidemics, plagues and pestilences were proved to be merely the ravages of micro-parasites; the life of the under world was scrutinized, classified and studied, and has been found to follow in general the same natural laws as that of the upper world. Bacteriology has given to us a comprehension of the under world similar to that which astronomy and astro-physics have given us of the heavens; the widely-accepted theory of present-day spontaneous generation has been proved to be a myth, and with the fading out of this ancient view of nature the last traces of medieval ideas of magic, alchemy and easy transmutation of the elements have disappeared from science.

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*CERTAIN STROBOSCOPIC PHENOMENA IN THE
END-ON PROJECTION OF A SINGLE WAVE.*

IN projecting a plane polarized wave machine wave, *ww*, with a lens on a distant screen, *S*, one observes when the wave is in vigorous motion that the balls appear on the screen as stationary objects, symmetrically disposed with reference to the axis of advance of the wave, or the direction of incident light, *LL*, and at distances apart corresponding to equal phase-differences. Clearly the same effect must be produced in rotating the circle of reference, *C*, if provided with balls, *a*, *b*, *c*—at equal angular distances apart on the circumference. As certain parts of this phenomenon are peculiar, I constructed a disk like *C* by soldering bright rods at right angles to its surface at *a*, *b*, *c*—with an axle at *C*.